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Continuation of Investigation of a Possible Rainfall Period Equal to One-ninth the Sun-spot Period.*

BY DINSMORE ALTER.

IN THE *Monthly Weather Review* for February, 1921, is published a preliminary report of the investigation of all the state averages of rainfall for the whole United States. Certain conclusions are reached tentatively, subject to further investigation. These are that there is evidence tending to show the existence of a correlation between rainfall and sun spots and that the rainfall follows a period of one-ninth the sun-spot period, varying its length always to keep in step with the sun-spot cycle. In this paper it is assumed that the reader is familiar with the previous discussion and only very brief reference will be made to any point discussed there. As stated in the conclusion of the other paper, the work has been continued in an attempt to fix more definitely the probability of the phenomenon.

The first continuation of the work was to answer definitely the question whether it might be that excessive rainfall or severe droughths in a very few of the months under discussion had produced the variations noted in the means of the two halves of the time as recorded in the previous paper. To do this, it was necessary to obtain the percentages of rainfall through each of the cycles for which data are available. For the eastern group state averages from two states are available beginning January, 1883, and for all states from the latter nineties. These averages give us twenty-four consecutive

* Received for publication August 5, 1921.

cycles. In investigating individual cycles it is necessary to eliminate the seasonal effect from each individual month. This has, therefore, been done for each month and each state by dividing the actual rainfall of each state for each month by the normal of that state and month. As stated in the first paper, this method is as reliable as the former one, except on the extreme western coast of the country where normals are practically zero for certain months, and where these zero months are thus given an equal weight with months of heavy normal rainfall. The results for these twenty-four consecutive cycles are tabulated as table 1. The attention of the reader is called to the fact that in twenty-two cycles there are only two in which the percentage of rainfall, for months when the cycle calls for a minimum, has actually been above normal. Each of these cycles is strictly independent of any other and their lengths are dependent only upon extra-terrestial causes. For the maximum phase it is to be noted that sixteen are above normal, seven below and one exactly normal. The author believes that this table establishes the probability much more strongly than the previous treatment, so strongly in fact that only very strong definite negative evidence can combat it.

California, western Washington and western Oregon are, as shown in the preceding paragraph, not available for treatment by individual cycles unless the summer months are entirely disregarded. It has been felt best, therefore, to treat, instead of the whole Pacific group of the first paper, the states of eastern Washington and Oregon, Idaho, Montana, Utah and Nevada as a unit. For these states there are available eighteen consecutives cycles. The results are shown as table 2. For the minimum phase fifteen of the eighteen are found to be below normal and for the maximum phase thirteen out of the eighteen are above normal.

As shown in the first paper, it is impossible to continue the varying period beyond the last date which is followed by both a sun-spot maximum and sun-spot minimum. This is 1913. The tables previously referred to are based on Wolfer's estimate of May, 1913, as epoch of minimum. This has been revised by him, placing the minimum nearly three months later.[1]

1. Prof. A. Wolfer. *Monthly Weather Review*, July, 1915, p. 314; August, 1920, pp. 459-461.

However, since the effect of changing this one date would affect only the latter part of tables 1 and 2, and since they were computed before the new estimate became available, I have merely inspected them to see approximately what the result of the shift in the latter cycles will be. The reader can see by such an inspection that this will make the results slightly more striking than they are at present.

It is desirable to make some use of the rainfall data since 1913 if possible. Since it is impossible to use the period which actually applies, it is only possible to use a constant periodicity and thus get some approximation to the truth, although some of the amplitude is certain to be damped. Every indication from the sun spots and rainfall was that the period averaged approximately fourteen months since the last sun-spot minimum. I have, therefore, plotted all the data of these two sections on the basis of such a constant periodicity. The results are given as table 3. These show once more the regularity with which the phases hold for each cycle, although, since the constant period is, of course, only an approximation to the true variable one, the same accuracy cannot be expected as has been found before. It should be noted that should the investigator be engaged in the entirely different problem of hunting for a possible date of a future minimum instead of, as in this paper, justifying the assumption of existence of the period, he would no longer be bound by this constancy, but could adjust the lengths as seemed best to fit the data in hand.

The mathematical reason for the greater reliability of minima in comparison with maxima is shown at once by table 10 of the first paper. The 15-month primary period has its minimum at phase 13.4 and its maximum at 5.9 in the Eastern group. The second harmonic has minima at 13.3 and at 5.8, with maxima at 2.0 and 9.5. The third harmonic has minima at 13.4, 8.4 and 3.4, with maxima at 10.9, 5.9 and 0.9. It is, therefore, evident that amplitude variation between these harmonics will have very little effect on the principal minimum, but that changes in relative intensity will shift the principal maximum from phase 6, its normal value, whenever the second harmonic gains in relative strength sufficiently, to a principal maximum between phases 1 and 2.

TABLE 1.—Eastern Group. Rainfall data for twenty-four consecutive cycles ending 1913. Sun-spot minimum occurs in phase 4.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
74	258	64	129	127	122	110	71	66	224	149	116	94	184	117
89	99	110	118	60	109	109	103	60	110	127	68	28	92	92
89	102	84	148	96	144	144	108	80	115	87	102	90	90	120
114	73	98	102	102	55	146	86	85	85	158	69	91	78	77
91	93	93	73	73	113	76	131	106	106	89	132	64	124	124
89	78	134	137	137	133	130	85	114	71	71	69	72	101	124
138	68	68	117	75	163	64	119	138	130	97	132	91	83	124
146	159	63	86	121	149	137	71	59	98	106	119	59	66	136
96	121	79	94	111	124	132	105	98	89	36	125	79	70	138
102	136	101	70	99	102	120	100	88	83	117	72	98	91	80
76	123	108	71	95	134	48	82	98	84	96	90	54	64	116
113	65	122	82	77	109	132	76	121	77	138	49	94	131	122
87	88	117	82	46	68	129	112	98	92	96	93	88	108	142
101	169	105	98	120	132	66	81	80	95	83	83	96	82	88
144	101	110	82	141	99	75	82	120	139	80	69	106	132	122
94	88	150	104	59	62	156	70	104	99	76	118	91	78	144
121	118	140	96	162	131	97	78	126	97	90	83	68	76	96
77	110	83	83	88	101	101	88	104	63	97	90	94	87	100
120	107	116	118	97	130	74	129	105	60	127	62	92	114	126
121	123	126	95	111	100	66	80	113	134	107	99	88	147	85
146	130	89	136	100	116	134	80	96	103	65	63	64	65	81
138	102	134	119	104	87	91	72	66	100	106	105	26	104	105
120	105	80	92	126	78	77	87	67	70	130	53	94	79	137
108	143	136	133	92	87	147	148	116	85	107	103	122	79	80
14	16	14	11	11	16	14	8	11	8	11	9	2	9	15 Above normal
10	8	10	13	12	7	10	15	13	15	13	15	22	15	8 Below normal
108	115	105	103	101	110	107	94	96	100	101	90	84	97	112 Mean

TABLE 2.—Rainfall data of six western states September, 1889, to April, 1913. Phase numbers same as for Eastern group.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
.....	.....	.....	*36	*255	*164	*409	200	120	146	66	106	67	38	318
114	50	14	70	45	187	105	94	147	250	215	86	128	28	46
169	62	54	106	119	127	106	85	28	30	71	122	128	69	125
156	127	47	86	44	174	113	124	94	138	116	156	91	101	82
67	109	82	30	141	150	94	85	76	69	68	43	118	26	82
116	115	62	120	149	61	126	137	88	74	198	85	80	160	118
67	119	100	55	108	146	167	138	64	87	72	161	100	76	80
63	82	86	104	116	126	91	89	86	56	211	62	151	100	79
81	70	188	86	54	45	108	115	164	113	86	123	72	86	97
78	62	74	133	78	65	120	51	141	100	104	44	173	68	54
40	154	130	117	47	100	86	84	92	112	107	82	126	63	76
190	206	93	67	69	109	67	64	103	26	96	71	69	118	97
119	109	57	53	131	98	102	65	114	98	130	109	169	134	75
162	86	57	152	171	155	132	156	98	95	181	108	180	90	83
51	139	65	91	102	66	145	132	121	110	121	190	43	68	190
127	72	69	77	109	160	157	80	188	136	110	125	73	82	70
82	84	47	140	133	148	95	148	93	62	79	111	149	61	74
161	99	92	83	108	82	104	158	111	109	174	172	94	148	85
101	88	91	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	8	2	7	12	11	13	9	9	8	11	11	9	5	4 Above normal
8	10	15	11	6	6	5	9	9	9	7	7	8	12	14 Below normal
108	102	74	92	101	118	113	112	107	100	122	108	112	84	102 Mean

* These months not used in mean since only one state's data available.

TABLE 3.—Rainfall since August, 1913, plotted as constant 14-month approximate periodicity.

EASTERN GROUP.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	
93	71	88	78	121	134	87	76	79	97	83	107	56	73	
86	118	73	105	91	130	144	102	44	44	130	95	114	144	
100	124	97	123	111	81	77	78	112	125	138	83	87	87	
74	102	108	72	127	95	86	110	102	95	95	121	31	53	
60	60	58	145	95	87	75	87	113	153	99	126	92	98	
116	91	146	101	112	109	65	188	138	86	98	88	107	161	
86	107	102	129	107	53	124	124	75	82	.....	.....	.....	.....	
1	4	3	5	5	3	2	4	4	2	2	3	2		2 Above normal.
5	3	4	2	2	4	5	3	3	5	4	3	4		4 Below normal.
88	96	96	108	109	98	94	109	95	97	107	103	81		101 Mean.

SIX WESTERN STATES.

80	192	150	142	94	124	134	90	163	97	47	145	70	213	
128	38	130	149	39	50	66	116	72	137	161	92	185	41	
119	50	120	136	172	142	146	78	80	116	184	108	72	150	
69	132	74	116	96	170	147	49	64	41	113	22	70	211	
110	105	97	64	64	89	164	141	156	156	75	96	61	162	
90	87	60	12	54	54	129	126	101	115	64	98	130	177	
69	98	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	
3	3	3	4	1	3	5	3	3	4	3	2	2		5 Above normal.
4	4	3	2	5	3	1	3	3	2	3	4	4		1 Below normal.
96	100	105	103	86	105	131	100	106	110	107	94	98		159 Mean*.

* Since these years averaged much wetter than normal the average of the phase means is 107 instead of 100.